Production of Solar Cells in Space from Non Specific Ores by Utilization of Electronically Enhanced Sputtering

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An ideal method of construction in space would utilize some form of the “Universal Differentiator” and “Universal Constructor” as described by Von Neumann (1).   The Universal Differentiator is an idealized non ore specific extractive device which is capable of breaking any ore into its constituent elements, and the Universal Constructor can utilize these elements to build any device with controllability to the nanometer scale. During the “Human Exploration Initiative” program in the early 1990s a conceptual study was done (2) to understand whether such devices were feasible with near term technology for the utilization of space resources and energy. A candidate system was proposed which would utilize electronically enhanced sputtering as the differentiator. Highly ionized ions would be accelerated to a kinetic energy at which the interaction between them and the lattice elections in the ore would be at a maximum. Experiments have shown that the maximum disintegration of raw material occurs at an ion kinetic energy of about 5 MeV, regardless of the composition and structure of the raw material. Devices that could produce charged ion beams in this energy range in space were being tested in the early 1990s. At this energy, for example an ion in a beam of fluorine ions yields about 8 uranium ions from uranium fluoride, 1,400 hydrogen and oxygen atoms from ice, or 7,000 atoms from sulfur dioxide ice. The ions from the disintegrated ore would then be driven by an electrical field into a discriminator in the form of a mass spectrometer, where the magnetic field would divert the ions into collectors for future use or used directly in molecular beam construction techniques. The process would require 10-7 Torr vacuum which would be available in space or on the moon. If the process were used to make thin film silicon solar cells (ignoring any energy inefficiency for beam production), then energy break even for solar cells in space would occur after 14 days.

(1) **Advanced Automation for Space Missions**, **NASA CP 2255**, **Proceedings of the 1980 NASA ASEE**, **Summer Study, Santa Clara California**

(2) **Curreri, P.A., General-Purpose Element-Extracting Process using Electronically Enhanced Sputtering, NASA Tech Briefs, pg. 70, October 1993.**

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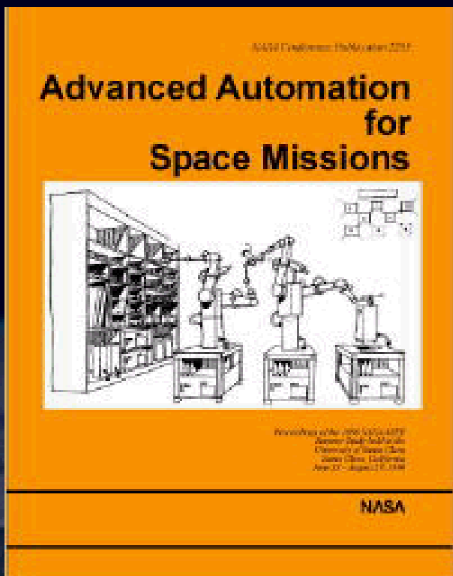
Center for Adv. Materials at U. Houston, Clear Lake Hilton, Houston Texas

26 October 2009

Super Automation using Space Resources



Advanced Automation for Space Missions
NASA CP 2255
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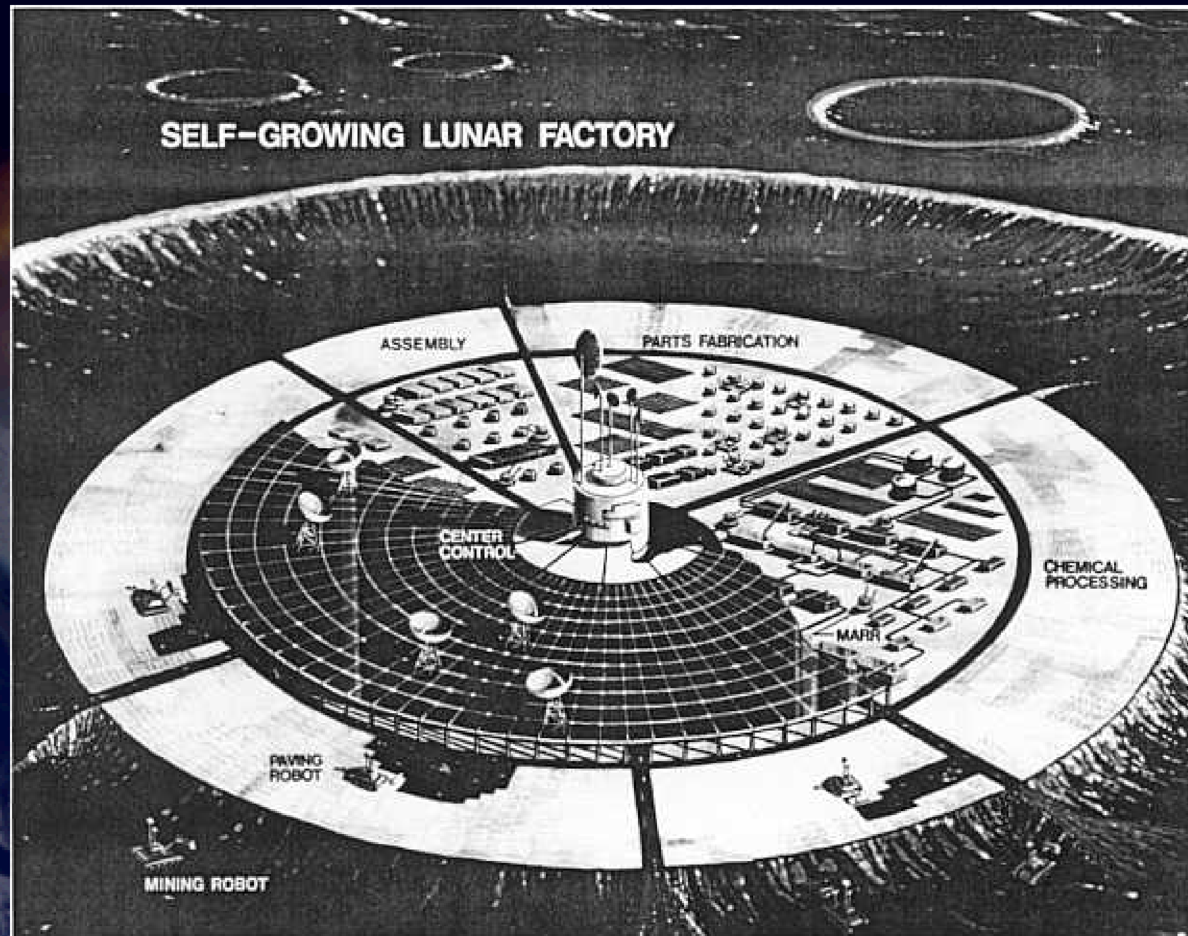
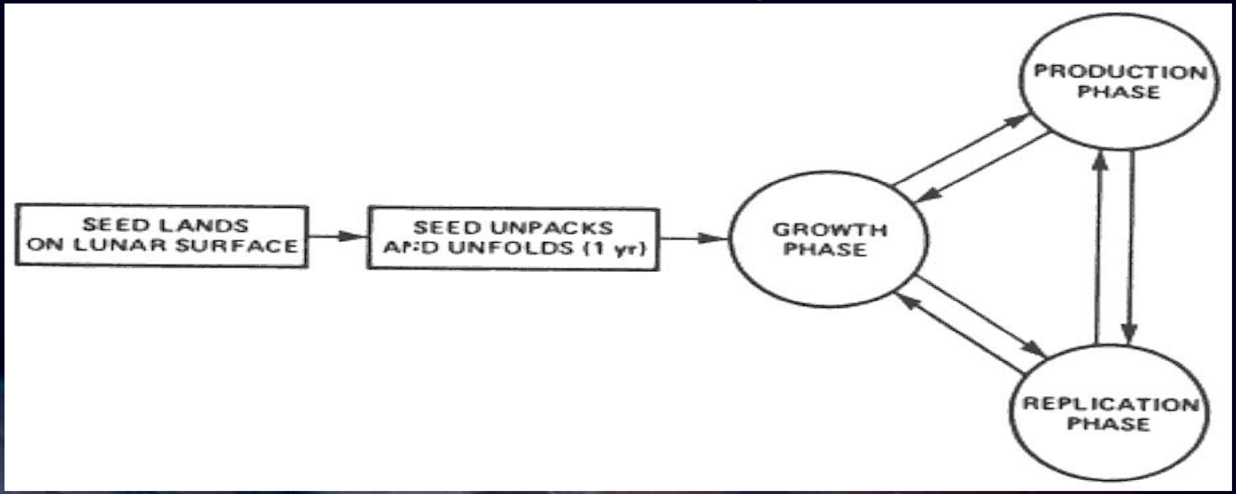
Summer Study, Santa Clara California



A Self Replicating Lunar Factory, R.A. Freitas and W. B. Zachary, Space Manufacturing 4, 1981

Self-Replicating Lunar Manufacturing Facility



- 100-ton seed (4 Apollo Landings) produces 100-tons same materials
- for simple exponential doubling growth
- $T = 1 + \log_2 N$, where T is elapsed time, N = number of seeds
- Then Productivity, P, in tons/year is, $P = 100*\log_2 N$
- If each unit works only on replicas and units cooperate in replication,
- We get "fast exponential" growth where $T = 1 + ½ + …+ 1/N$
- In 18 years expansion we have 4 billion tons which is roughly the entire industrial out put of humanity (1980).

A Self Replicating Lunar Factory, R.A. Freitas and W. B. Zachary, Space Manufacturing 4, 1981

What would be the Ideal technology for construction in Space?

- Robots in the Desert Story

- Universal Differentiator
  – Has the ability to take any ore or other complex material and break it down into into its constituent elements

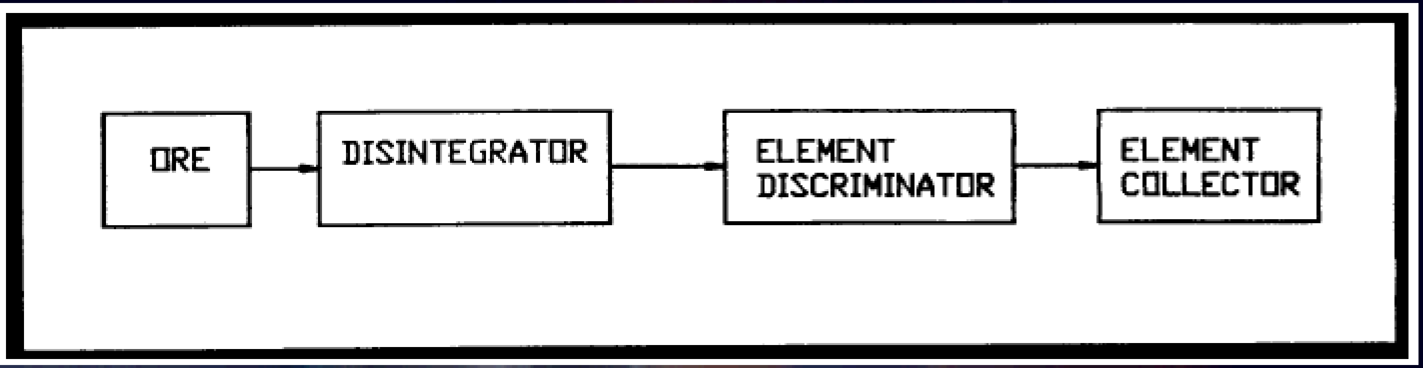
- Universal Constructor
  – Has the ability to construct any device including a copy of itself from a soup of elements of constituent parts

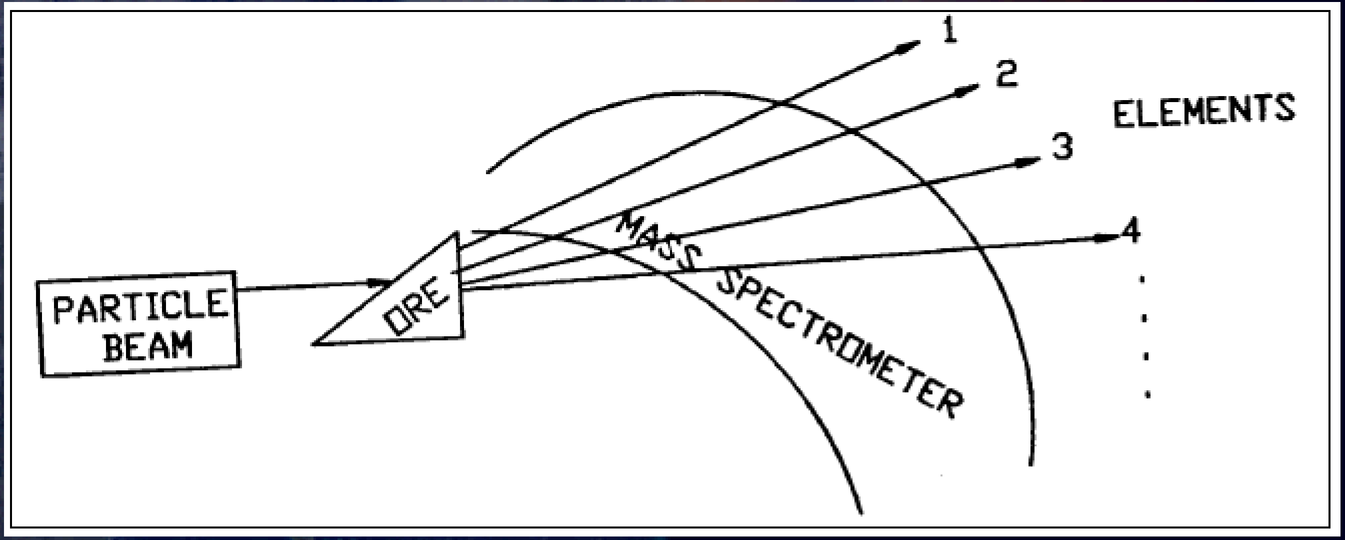
John von Neumann
Los Alamos

- With sufficient material and energy Space industrial capacity develops exponentially

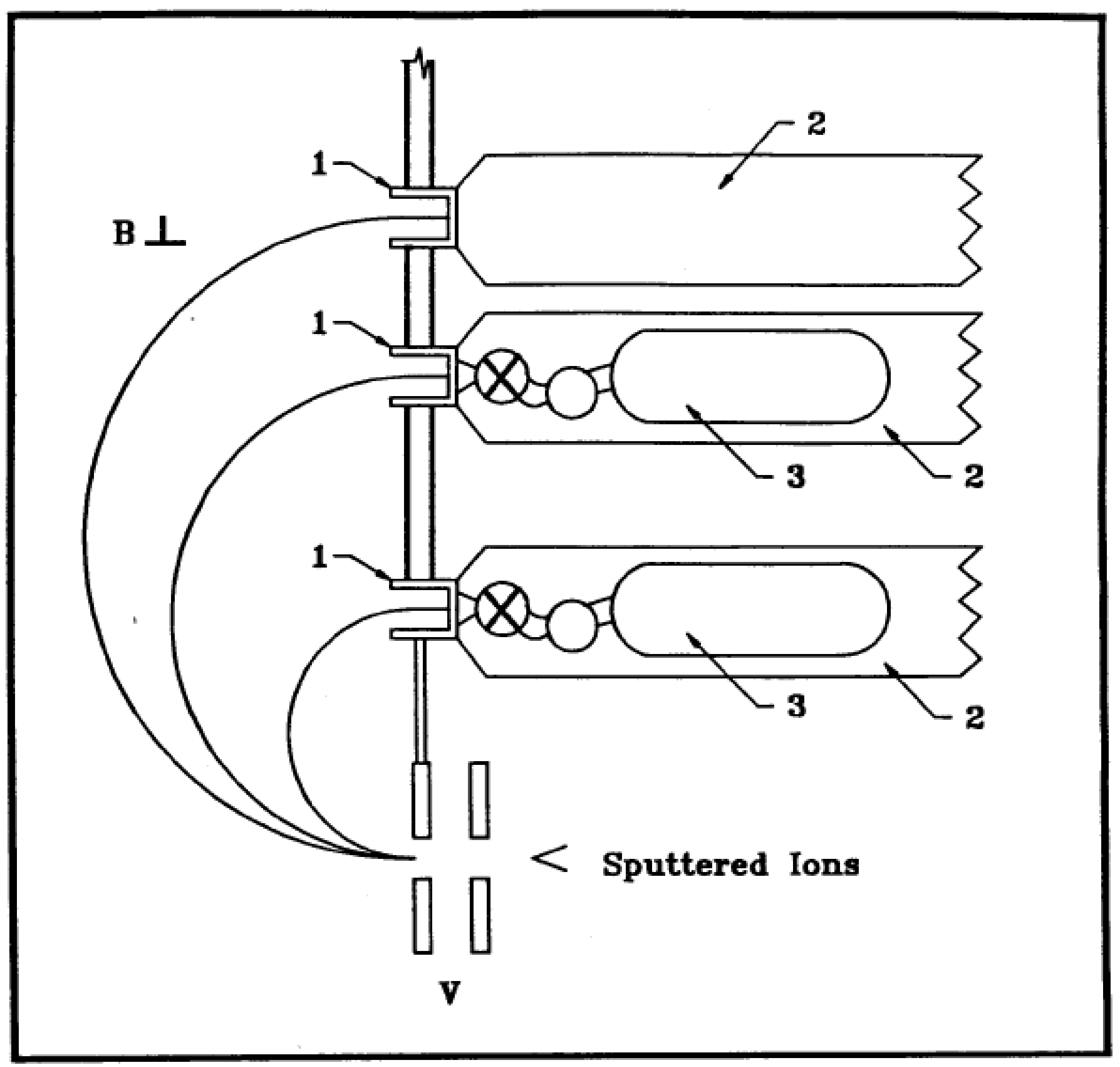
Adv. Automation for Space Missions, Ed. by Robert Freitas, NASA CP 2255 (1980).

Schematic view of a particle beam differentiator

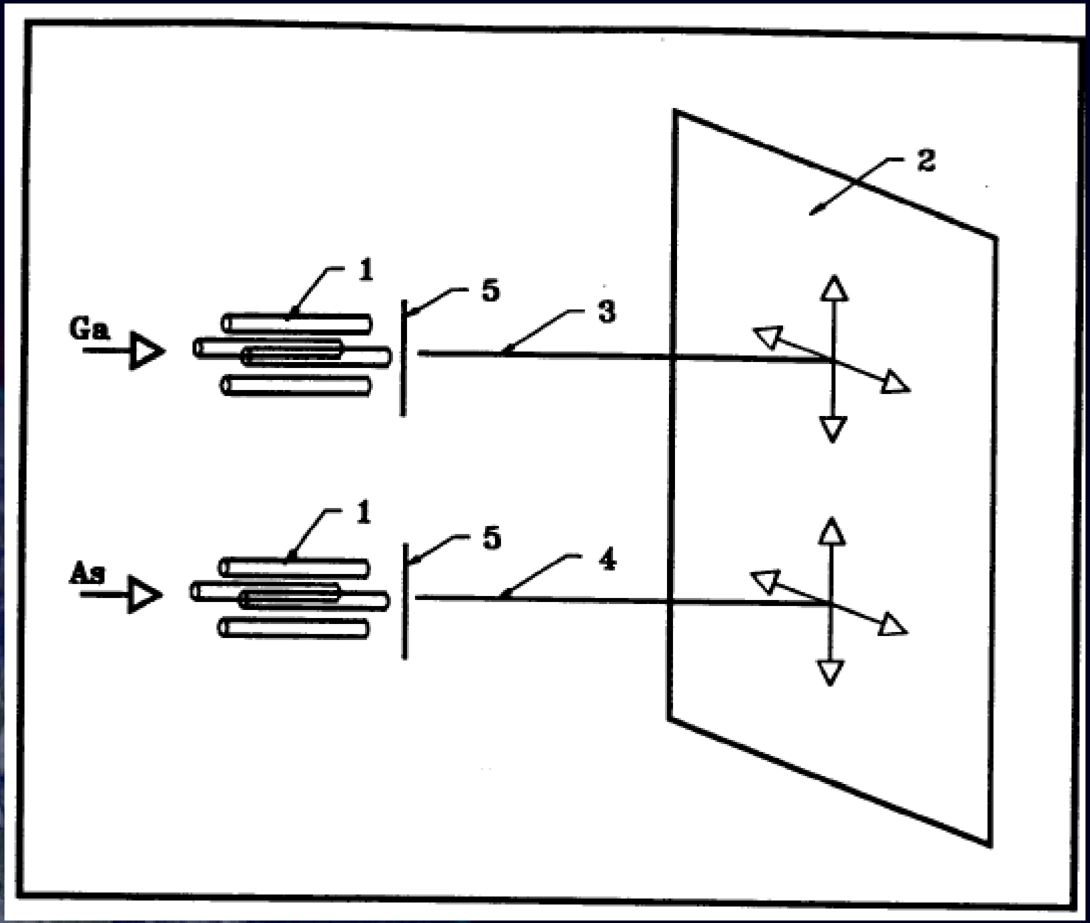




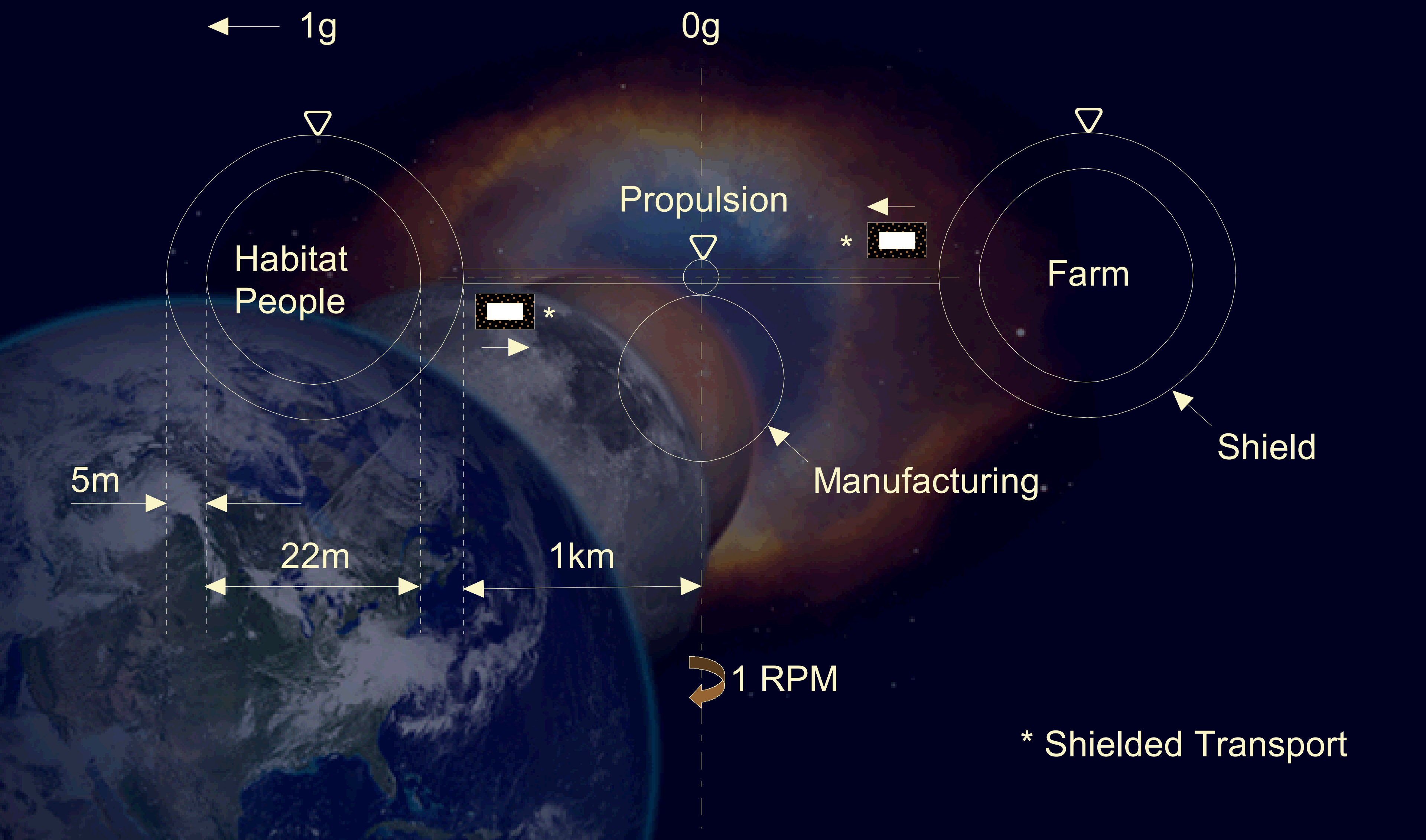
Schematic view of an element collector



Schematic view of a molecular beam assembler



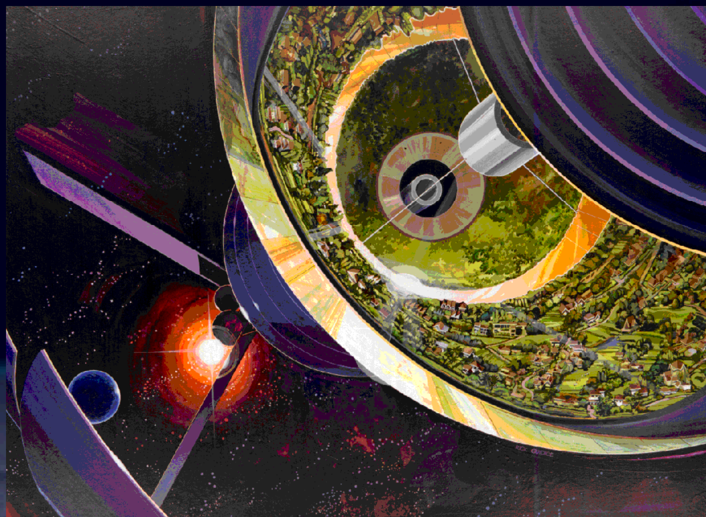
Humans in the Loop Self-Reproducible Self-Sufficient Habitat in Free Space

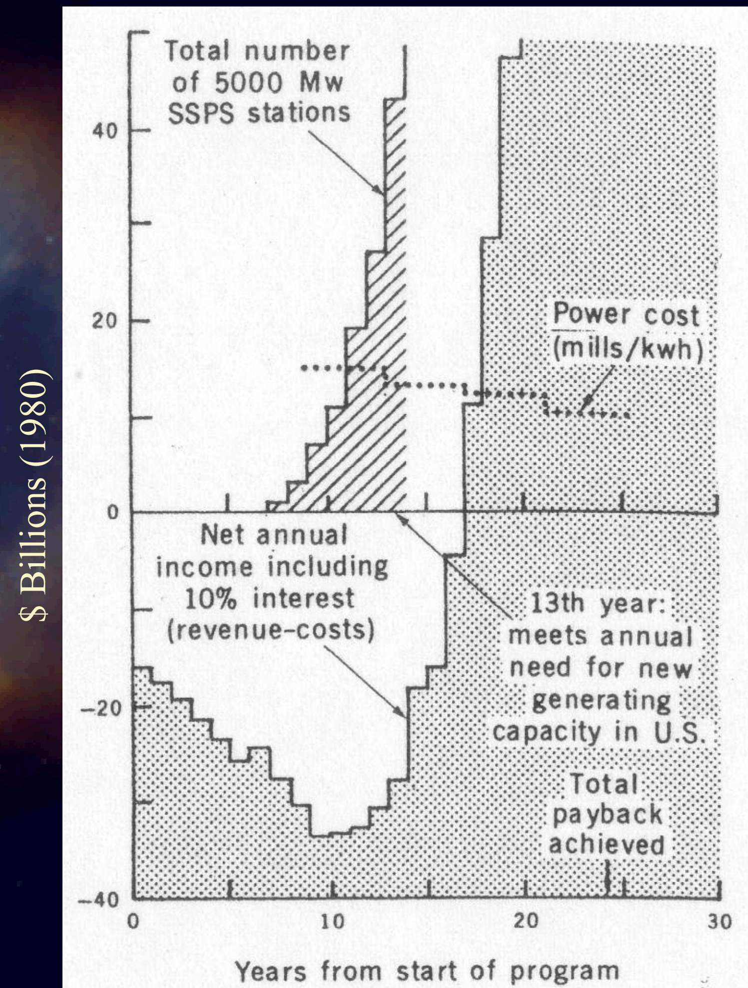


Curreri, P.A., “A Minimized Technological Approach towards Human Self Sufficiency off Earth,” in CP880, STAIF 2007, edited by M. S. El-Genk, AIP CP880, pgs. 904-910, 2007.

Habitat Geometry	Number of People/unit	Planned US Launch capability	Testable on the Moon
O’Neill Cylinders	2,000,000	Beyond	No
Bernal sphere	20,000	Beyond	No
Stanford Torus	10,000	Beyond	No
Bolo (1975)	200	Difficult	Difficult
Homestead Bolo	10	Yes	Yes

Affordable Space Solar Power + Human Colonies in Free Space Built using Lunar and Asteroid Materials





Senate Committee on Aero and Spa. Sci. Dr. O'Neill, 1976

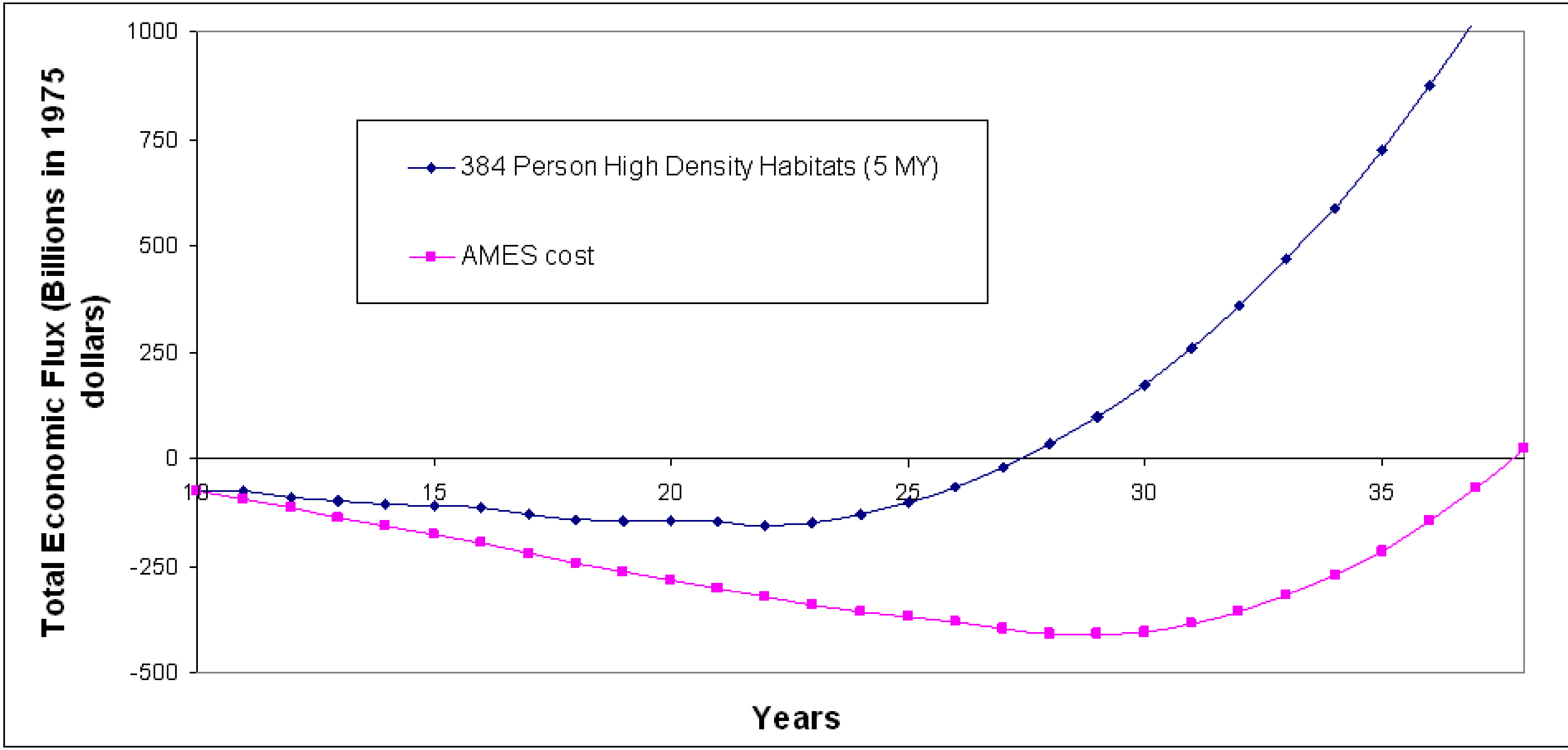
Sun pumps out 4 x 10^{26} watts (40 million times the needs of even a projected Solar System Society).

Solar Power Satellite – “the killer app.”

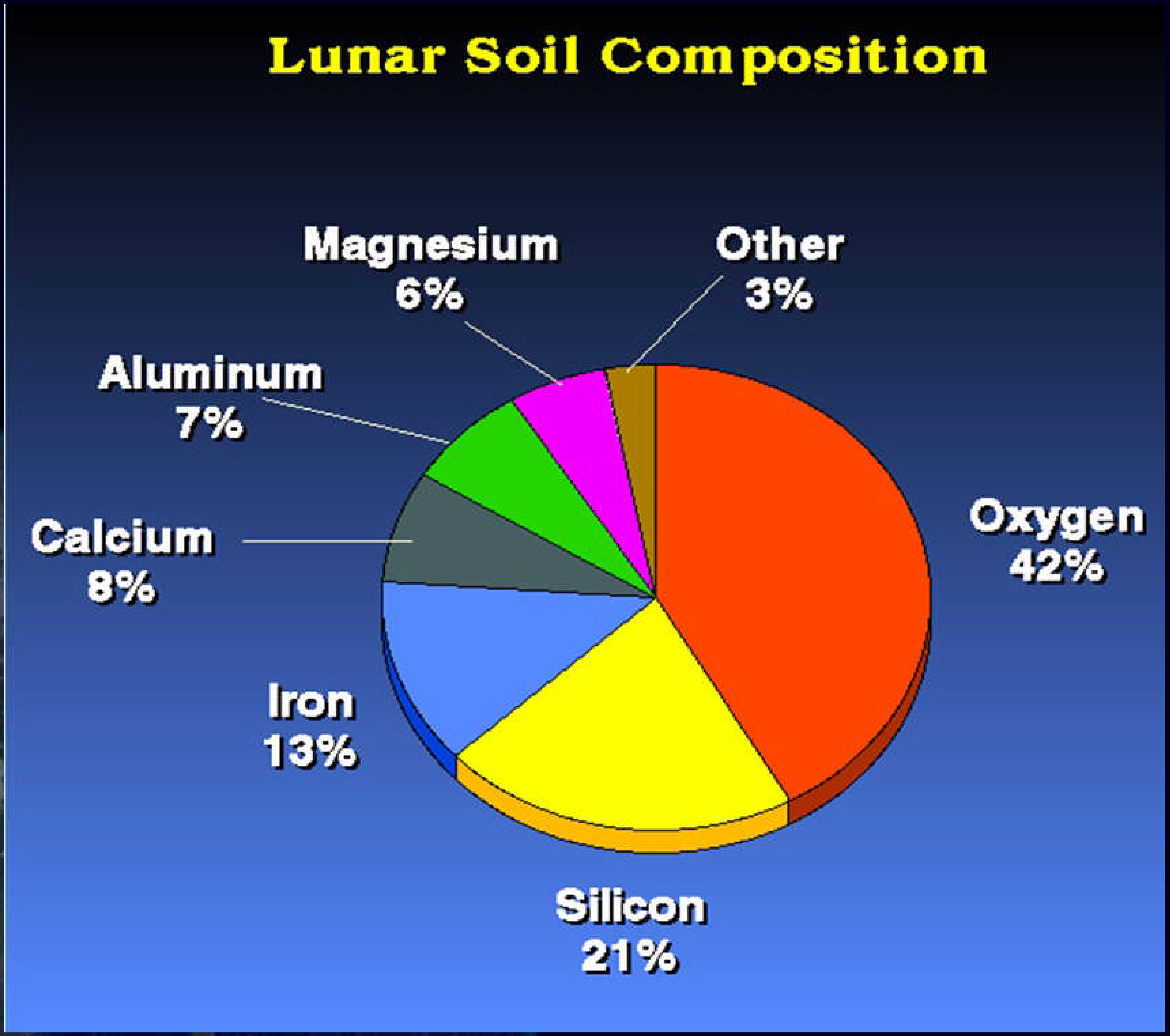
Space Solar Power Satellite suggested by Dr. Peter Glasser in 1968
21 by 5 km Satellite would provide 10 GW to Earth by Microwave Beam

“No alternative at all was found to the manufacture of solar satelli
Plants as the major commercial enterprise of the colony.”
Johnson, R. D. and Holbrow, C., eds., *Space Settlements, a Design Study*, SP-413, NASA, Washington, D.C. 197

The Economic Advantage of Beginning with Small Permanent Space Habitats



A Comparison of small bolos to the 1975 NASA Ames project using an almost identical model (1975 economics). This shows the economic benefit of early spaced based labor achieved through smaller permanent habitats.


Lunar Soil Composition
Magnesium
6%
Other
3%
Aluminum
7%
Calcium
8%
Oxygen
42%
Iron
13%
Silicon
21%

Engineering with Lunar Elements

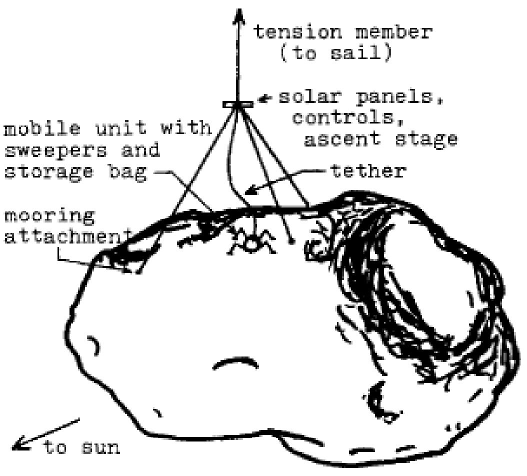
Lunar Elements Only						Material Class	Lunar Elements Plus ~ 5% or Less Earth Imports				
High Capacity				Limited Capacity			High Capacity				Limited Capacity
Al	Mg	Fe	Ti	Cr	Ni	Structural Metals	Al	Mg	Fe	Ti	Cr
Wrgt EC 1060 1100 3003 5005 5050 5052 5056 5083 5086 5154 5357 6063 6101 6151 Cast A13 43 214 220 356 360 Al Mag 35	AM10 0 M1A A3A	1020 1095 1340 5140 A24 2 X70 9260 501	99.2 99 Ti- 8Mn 4-4 Al/M n	S Steel 410 430 Nichrom e	Z-Ni Permalloy Permendu r 200 201 211 212 Inconel 600 702 721 722		7075 7178 MA67 MA87	ZK60 AZ80A	404 2 434 0 864 0 6B	6-4 Al/V 5-2.5 Al/Sn 7-4 Al/Mo 6-2-4-2 Al/Sn/ Zr/Mo	SS 440C 446

Engineering with Lunar Elements 2

Al_2O_3 in Al, Mg Fe, Glass in Mg, $TiSSi_3$ in Ti	Al_2O_3 in Ni SiO_2 in Ni	Reinforced metals		
Cast Basalt Dark Glass Foamed Glass		Structural non metals		
Al_2O_3, CaO, MgO, TiO_2, SiO_2, Spinels, Mixed ceramics, "S" fiber, $TiSSi_3$	Cr_2O_3, K_2TiO_3	Thermal materials, refractorys, insulation, fibers		
		Electric / magnetic Materials		
Fe, Al, Mg	Ni-Cr	Conductors		
Kanthal A-1		Restistance alloys		
Si	AlP, FeS_2, NiO, CoO	Semicondu ctors		
Same as thermal except $TiSSi_3$) + titnates		Dieletrics / ins.		
Fe, Si—steels (M15, M5-8) Fe_3O_4, $MgFe_2O_4$, sendust	Permalloy Permendur Cr)3	Magnetics		
Fe_3O_4, TiO		Electrodes		
Same as refractorys except CaO + garnets		Abrasives		SiC(30%) TiC(20%)
O_2, O_3	SO_2, SO#, CrO_3	Fluid / Volatiles, Cryogenic ambient mp < 500 CNaH	H_2O (11%), H_2O_2 (6%), H_2SO_4, H_2SO_3, H_3PO_4	H_2S(6%), H_3P(9%) NaOH

Waldin and Crisswell

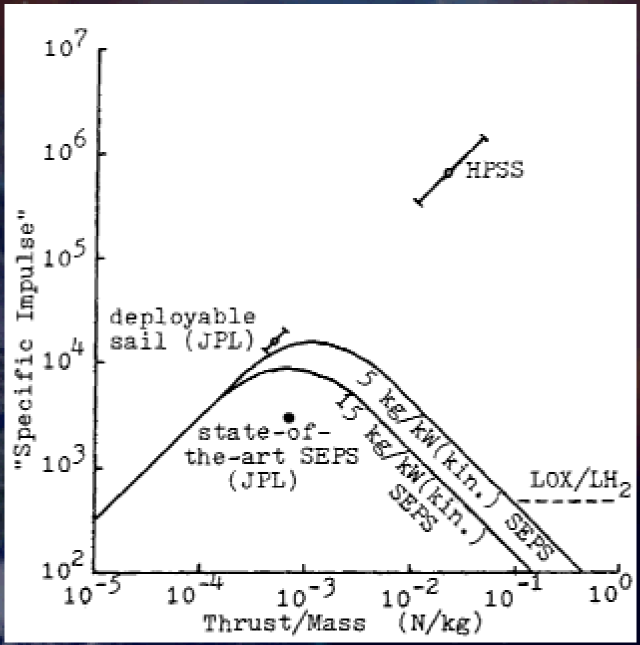
In Space Propulsion using Space Resources



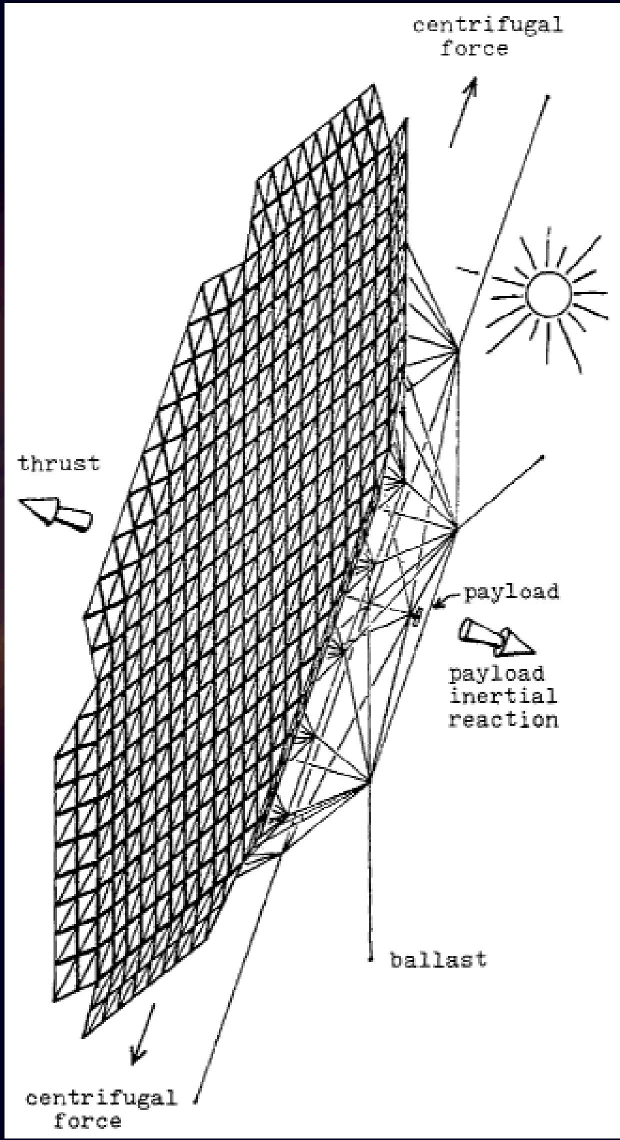
Near Earth Asteroid

Nuclear Steam Engine
Space Propulsion Economy

Ultra Thin (2-3 micron)
Ultra large surface area



Ultra high performance solar sails –
Thinner and higher surface area
Than practical to launch from Earth

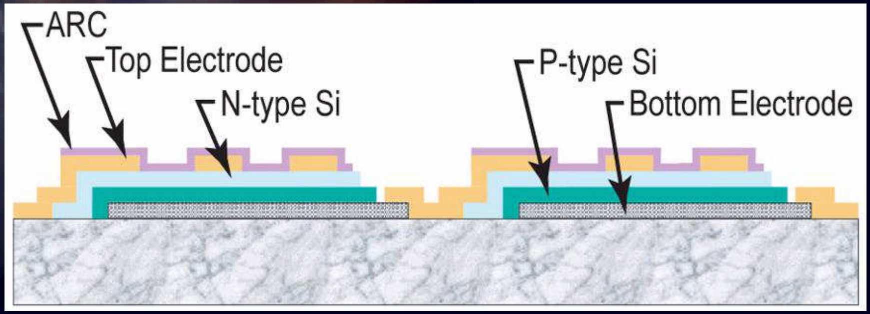


From K.E. Drexler, MIT, 1979

Advances in Power Production Example:
Lunar Photovoltaic Power

- Small Rover evaporates lunar regolith thin films on lunar glass
- Predicted Energy Break Even < 1 Lunar Day
- Predicted Grown Power > 100 KW / year / rover

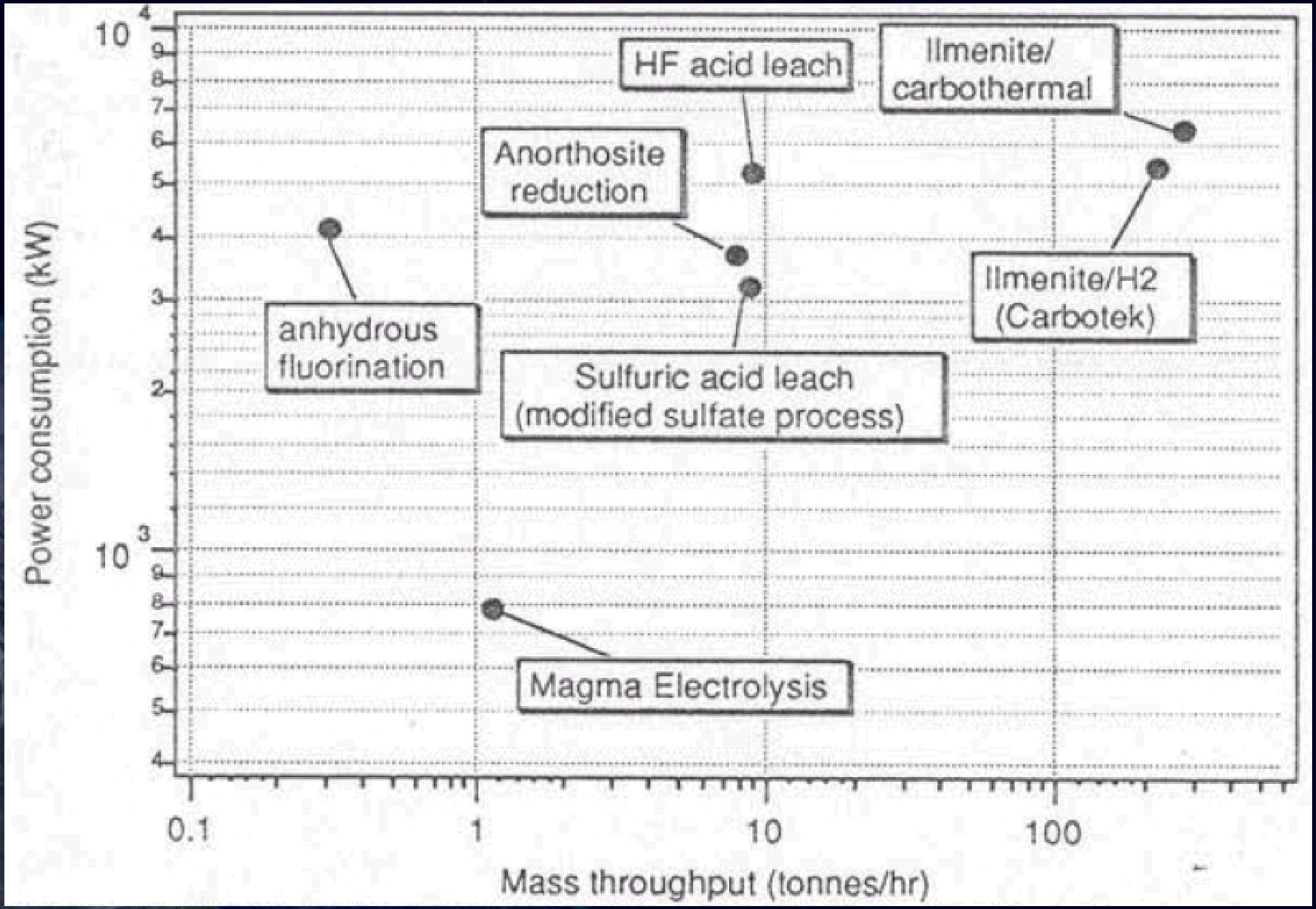
Lunar Solar Cell Producing Rover Concept



Solar Cell Structure

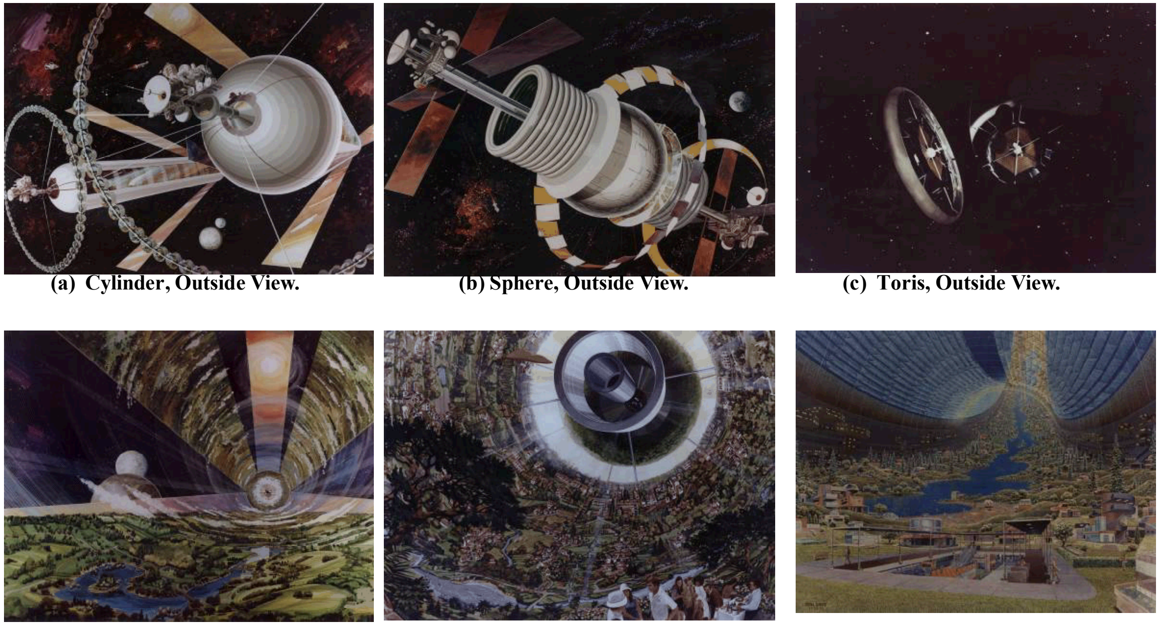
Freundlich, Ignatiev, Horton, Duke, Curreri, Sibille, Manufacturing of Solar Cells on the Moon, in 31st IEEE PSC,p. 794, 2005

Production of O_2 from Lunar Regolith (1 kT O_2/yr basis)



(From L.W. Mason, in Space 92, p.1139, ASCE (1992))

GROWTH INTO TOWNS AND CITIES



(a) Cylinder, Outside View.
(b) Sphere, Outside View.
(c) Toris, Outside View.
(d) Cylinder, Inside View.
(e) Sphere, Inside View.
(f) Toris, Inside View.